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Seminars in ULTRASOUND CT and MRI

Anatomy of the Temporomandibular Joint

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The temporomandibular joint (TMJ), also known as the mandibular joint, is an ellipsoid variety of the right and left synovial joints forming a bicondylar articulation. The common features of the synovial joints exhibited by this joint include a fibrous capsule, a disk, synovial membrane, fluid, and tough adjacent ligaments. Not only is the mandible a single bone but the cranium is also mechanically a single stable component; therefore, the correct terminology for the joint is the craniomandibular articulation. The term temporomandibular joint is misleading and seems to only refer to one side when referring to joint function. Magnetic resonance imaging has been shown to accurately delineate the structures of the TMJ and is the best technique to correlate and compare the TMJ components such as bone, disk, fluid, capsule, and ligaments with autopsy specimens.
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The most important functions of the temporomandibular joint (TMJ) are mastication and speech and are of great interest to dentists, orthodontists, clinicians, and radiologists. This interest stems from the standpoints of structure, function, adaptability, symptomatology, pathology, and imaging.

The TMJ is a ginglymoarthrodial joint, a term that is derived from ginglymus, meaning a hinge joint, allowing motion only backward and forward in one plane, and arthrodia, meaning a joint of which permits a gliding motion of the surfaces.[1] The right and left TMJ form a bicondylar articulation and ellipsoid variety of the synovial joints similar to knee articulation.[2]

The common features of the synovial joints exhibited by this joint include a disk, bone, fibrous capsule, fluid, synovial membrane, and ligaments. However, the features that differentiate and make this joint unique are its articular surface covered by fibrocartilage instead of hyaline cartilage. Movement is not only guided by the shape of the bones, muscles, and ligaments but also by the occlusion of the teeth, since both joints are joined by a single mandible bone and cannot move independently of each other.

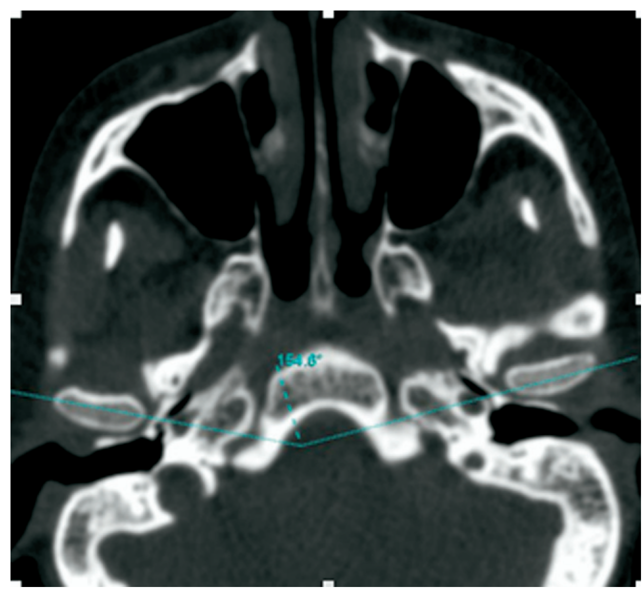

Figure 1 Perpendicular axial CT imaging in both condyles. The blue line represents the angle formed between the right and left condyle. The normal value is between 145 and 160°. (Color version of figure is available online.)

Articular Surfaces

Mandibular Component

This component consists of an ovoid condylar process seated atop a narrow mandibular neck. It is 15 to 20 mm side to side and 8 to 10 mm from front to back. Thus, if the long axes of two condyles are extended medially, they meet at approximately the

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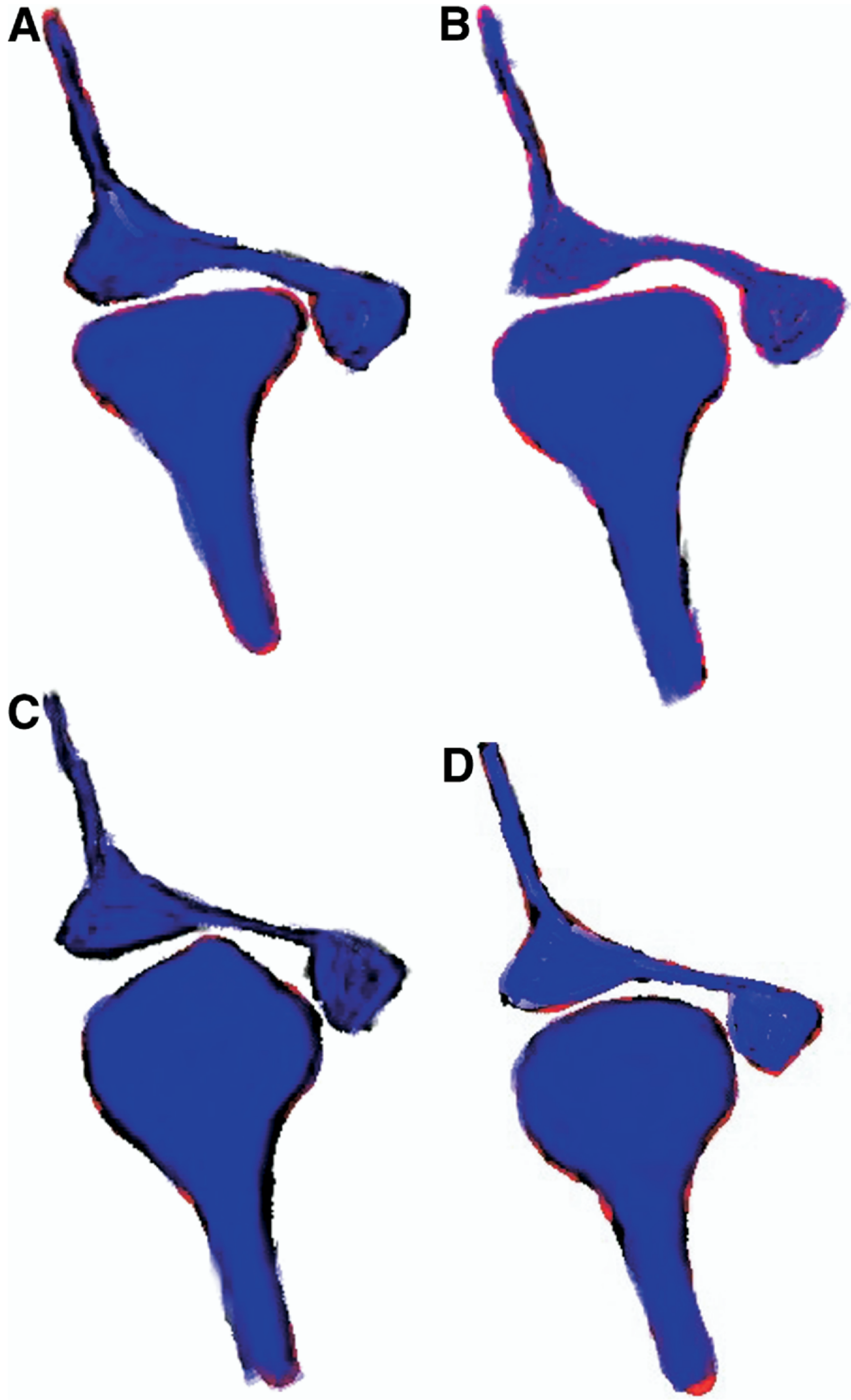

Figure 2 Variations in the morphologic architecture of the mandibular condyle in coronal plane, observed over a sample of 2950 TMJ (adapted from Yale SH[3]). (A) Type A morphology: 25%. (B) Type B morphology: 60%. (C) Type C morphology: 12%. (D) Type D morphology: 3%. (Color version of figure is available online.)

basion on the anterior limit of the foramen magnum, forming an angle that opens toward the front ranging from 145° to 160° (Fig. 1). The lateral pole of the condyle is rough, bluntly pointed, and projects only moderately from the plane of ramus, while the medial pole extends sharply inward from this plane. The articular surface lies on its anterosuperior aspect, thus facing the posterior slope of the articular eminence of the temporal bone. It further continues medially down and around the medial pole of the condyle to face the entoglenoid process of the temporal bone where the jaw is held in an occluded position.

The appearance of the mandibular condyle varies greatly among different age groups and individuals. Morphologic changes may occur on the basis of simple developmental variability as well as remodeling of the condyle to accommodate developmental variations, malocclusion, trauma, and other developmental abnormalities[3] (Figs. 2 and 3). The morphology of

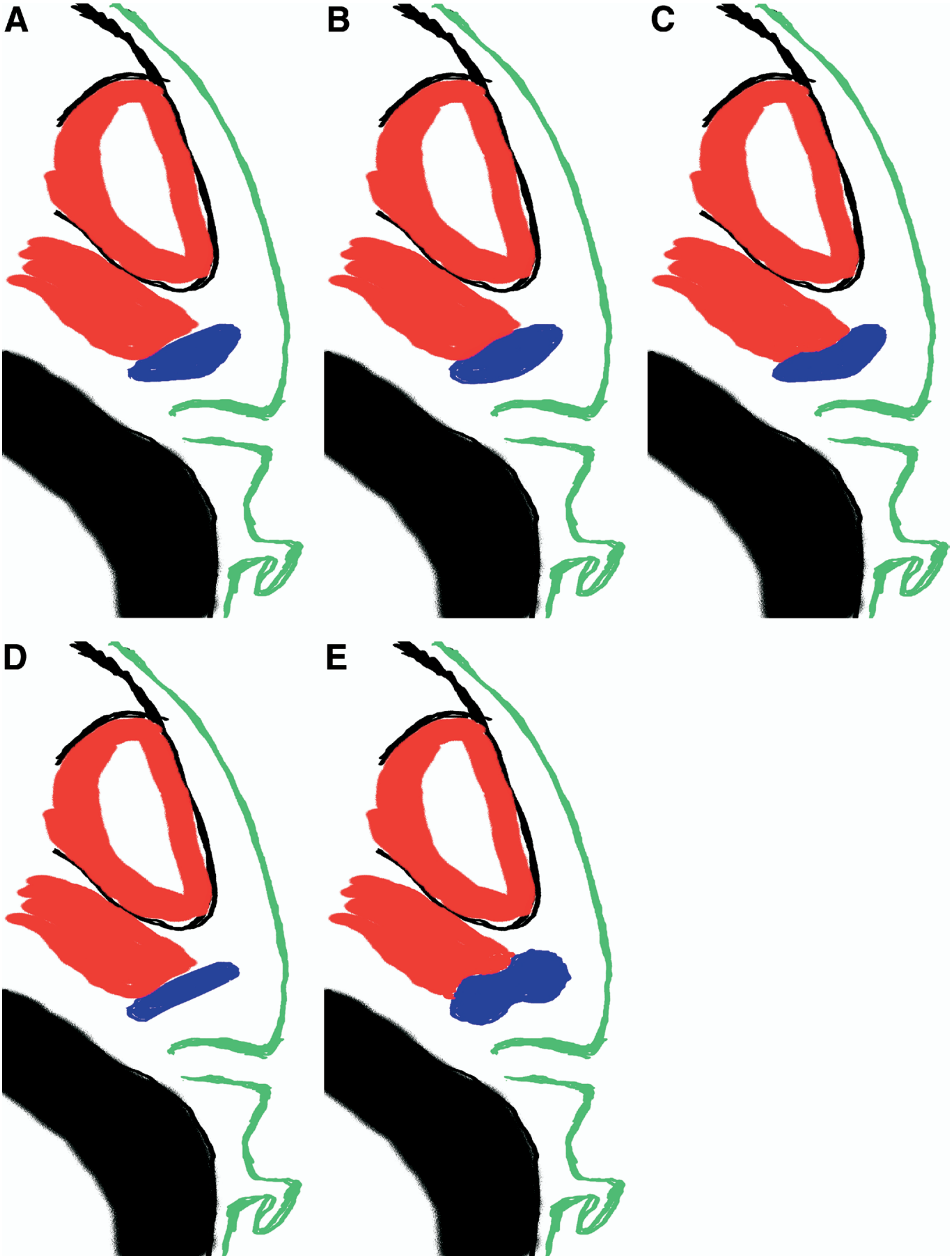

Figure 3 Variations in the morphologic architecture of the mandibular condyle in axial plane, observed over same sample of TMJ (adapted from Yale SH[3]). (A) Anterior side flat, posterior side convex: 44%. (B) Biconvex: 28%. (C) Anterior side concave, posterior side convex: 22%. (D) Flat: 5%. (E) Biconcave: 3%. (Color version of figure is available online.)

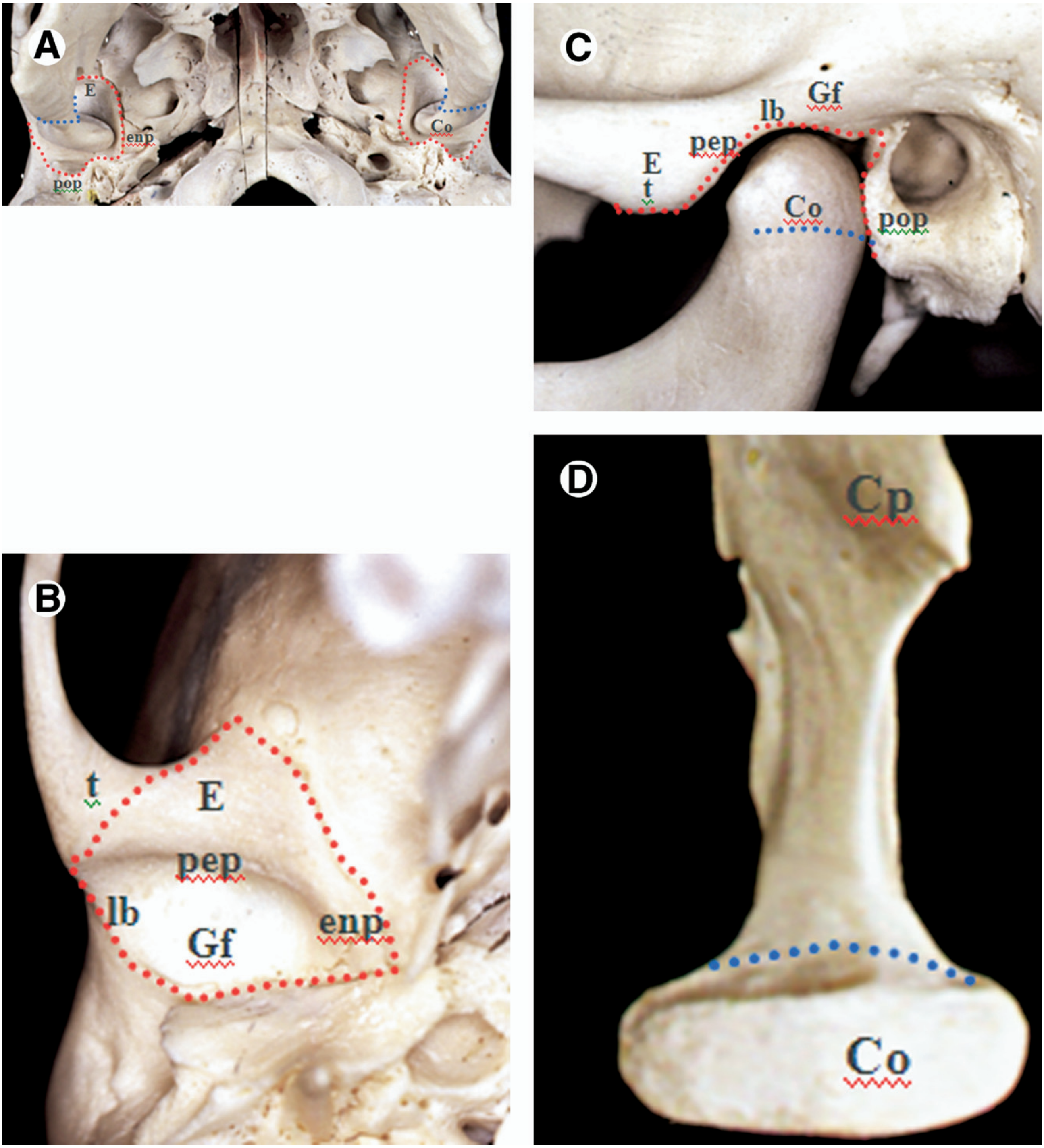

Figure 4 Bone anatomy and synovial insertion of the two components of the TMJ. Red line: capsular insertion in the temporal bone. Blue line: capsular insertion in the condyle neck. E: Articular eminence; enp: entogolenoid process; t: articular tubercle; Co: condyle; pop: postglenoid process; lb: lateral border of the mandibular fossa; pep: preglenoid plane; Gf: glenoid fossa; Cp: condylar process. (A) Caudal cranial view of the TMJ bone. (B) Caudal cranial view of the TMJ without the condyle. (C) Lateral view of the TMJ bone. (D) Cranial caudal view of the condyle bone without the cranial bone. (Color version of figure is available online.)

the condyle may be observed by axial and coronal magnetic resonance (MR) imaging.

Cranial Component

The articular surface of the temporal bone is situated on the inferior aspect of temporal squama anterior to tympanic plate. Various anatomical terms of the joint are elaborated below.

(a) Articular eminence: This is the entire transverse bony bar that forms the anterior root of zygoma. This articular surface is most heavily traveled by the condyle

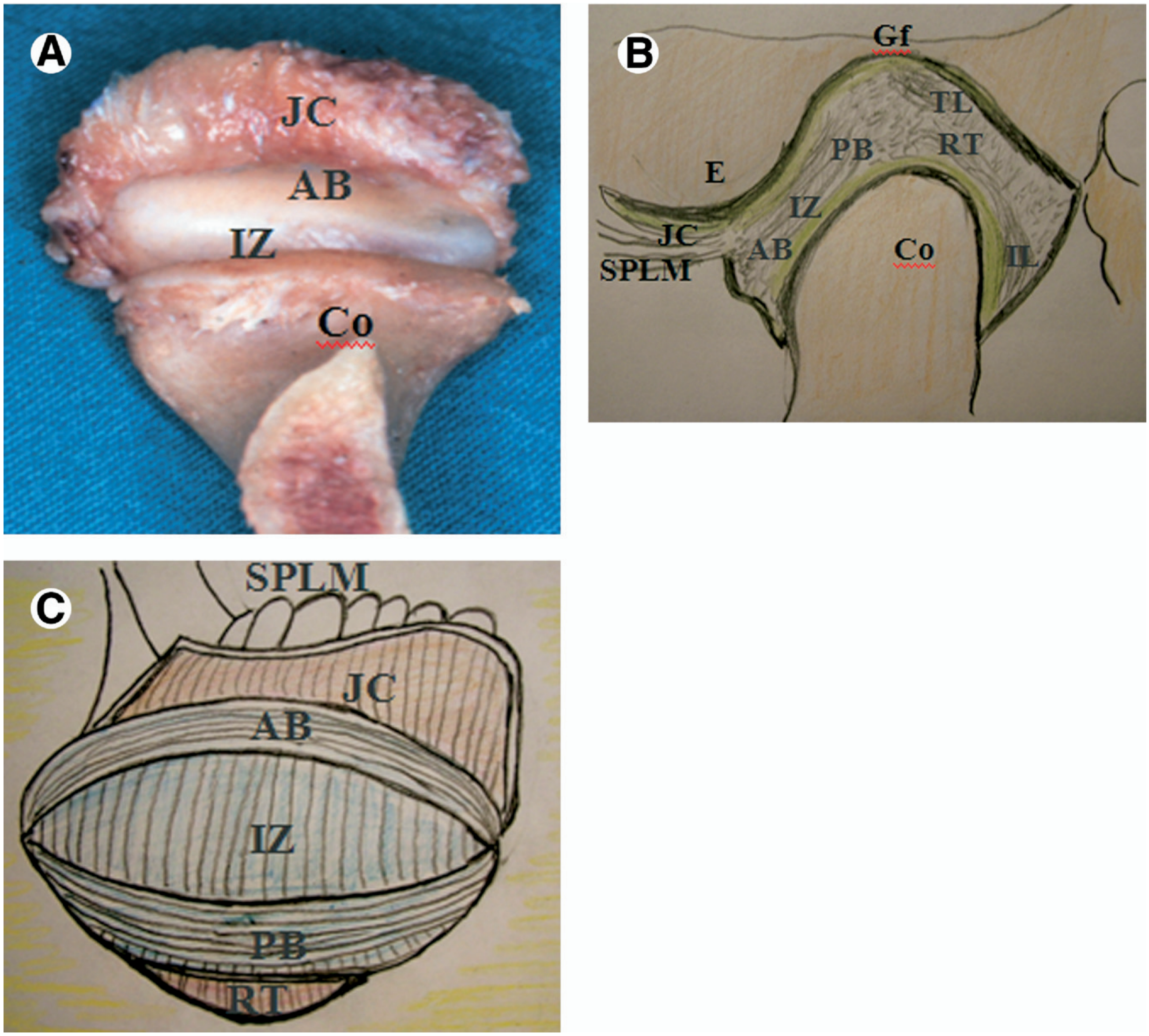

Figure 5 Components of the disk. AB: Anterior band; IZ: intermedius zone; PB; posterior band; SPLM: superior pterigoide lateral muscle; RT: retrodiskal tissue; TL: temporal lamina; IL: inferior lamina; JC: joint capsule; Gf: glenoid fossa; E: articular eminence; Co: condylar head of the mandible. (Color version of figure is available online.)

and disk as they ride forward and backward in normal jaw function.

(b) Articular tubercle: This is a small, raised, rough, bony knob on the outer end of the articular eminence. It projects below the level of the articular surface and serves to attach the lateral collateral ligament of the joint.

(c) Preglenoid plane: This is the slightly hollowed, almost horizontal, articular surface continuing anteriorly from the height of the articular eminence.

(d) Posterior articular ridge and the postglenoid process: The tympanosquamosal suture is divided by the protruding inferior edge of the tegmen tympani into an anterior petrosquamosal and a posterior petrotympanic fissure. The posterior part of the mandibular fossa is an anterior margin of the petrosquamous suture and is elevated to form a ridge known as the posterior articular ridge or lip. This ridge increases in height laterally to form a thickened cone-shaped prominence called the post glenoid process immediately anterior to the external acoustic meatus.

(e) Lateral border of the mandibular fossa: This structure is usually raised to form a slight crest joining the articular tubercle, in front, with the postglenoid process behind.

(f) Medially the fossa narrows considerably and is bounded by a bony wall that is the *entoglenoid process*, which passes slightly medially as the medial glenoid plane.

The roof of the mandibular fossa, which separates it from the middle cranial fossa, is always thin and translucent, even

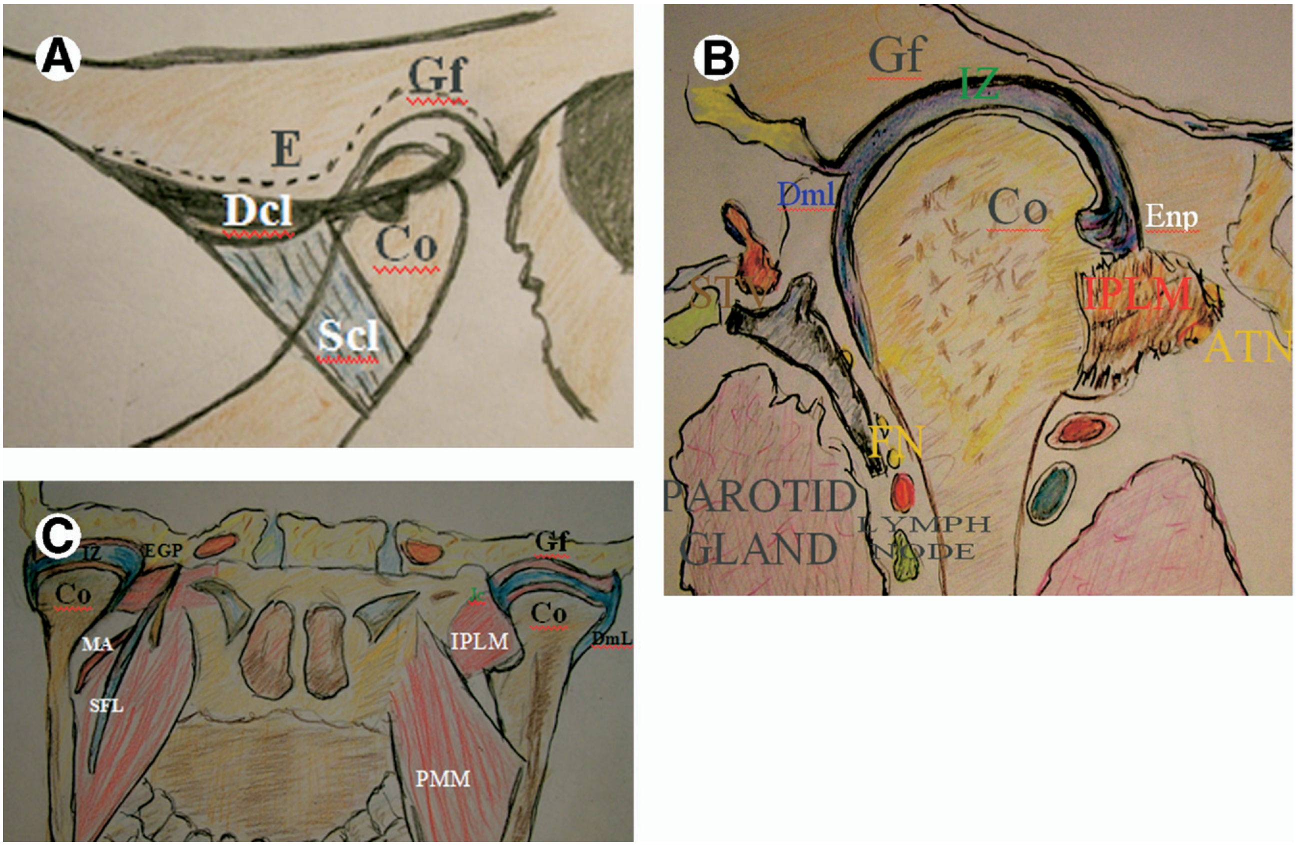

Figure 6 Dml: collateral disko-mandibular ligaments of the TMJ; Scl: superficial collateral ligament; Dcl: deep collateral ligament; Gf: glenoid fossa; E: articular eminence; IZ: intermedius zone; IPLM: inferior pterigoid lateral muscle; FN: branches of the facial nerve; ATN: auriculotemporal nerve; MA: maxillary artery; Co: condylar head of the mandible; SFL: sphenomandibular ligament. (A) Schematic view of the TMJ ligaments in the sagittal plane. (B) Schematic view of the TMJ disk and ligaments in the coronal plane. (C) Schematic view of both TMJ muscles and ligaments in the coronal plane. (Color version of figure is available online.)

in the heavy skull. This demonstrates that, although the articular fossa contains the posterior rim of the disk and the condyle, it is not a functionally stress-bearing part of the craniomandibular articulation[4] (Fig. 4).

Articular Disk

The articular disk is the most important anatomic structure of the TMJ. It is a biconcave fibrocartilaginous structure located between the mandibular condyle and the temporal bone component of the joint. Its functions to accommodate a hinging action as well as the gliding actions between the temporal and mandibular articular bone.

The articular disk is a roughly oval, firm, fibrous plate with its long axis being traversely directed. It is shaped like a peaked cap that divides the joint into a larger upper compartment and a smaller lower compartment. Hinging movements take place in the lower compartment and gliding movements take place in the upper compartment.

The superior surface of the disk is said to be saddle-shaped to fit into the cranial contour, while the inferior surface is concave to fit against the mandibular condyle.

The disk is thick, round to oval all around its rim, divided into an anterior band of 2 mm in thickness, a posterior band 3 mm thick, and thin in the centre intermediate band of 1 mm thickness. More posteriorly there is a bilaminar or retrodiskal region. The disk is attached all around the joint capsule except for the strong straps that fix the disk directly to the medial and lateral condylar poles, which ensure that the disk and condyle move together in protraction and retraction.[2] The anterior extension of the disk is attached to a fibrous capsule superiorly and inferiorly. In between it gives insertion to the lateral pterygoid muscle where the fibrous capsule is lacking and the synovial membrane is supported only by loose areolar tissue.

The anterior and posterior bands have predominantly transversal running fibers, while the thin intermediate zone has anteroposteriorly oriented fibers. Posteriorly, the bilaminar region consists of two layers of fibers separated by loose connective tissue. The upper layer or temporal lamina is composed of elastin and is attached to the postglenoid process, medially extended ridge, which is the true posterior boundary of the joint. It prevents slipping of the disk while yawning. The inferior layer of the fibers or inferior lamina curve down behind the condyle to fuse with the capsule and back of the condylar neck at the lowest limit of the joint space. It prevents excessive rotation of the disk over the con-

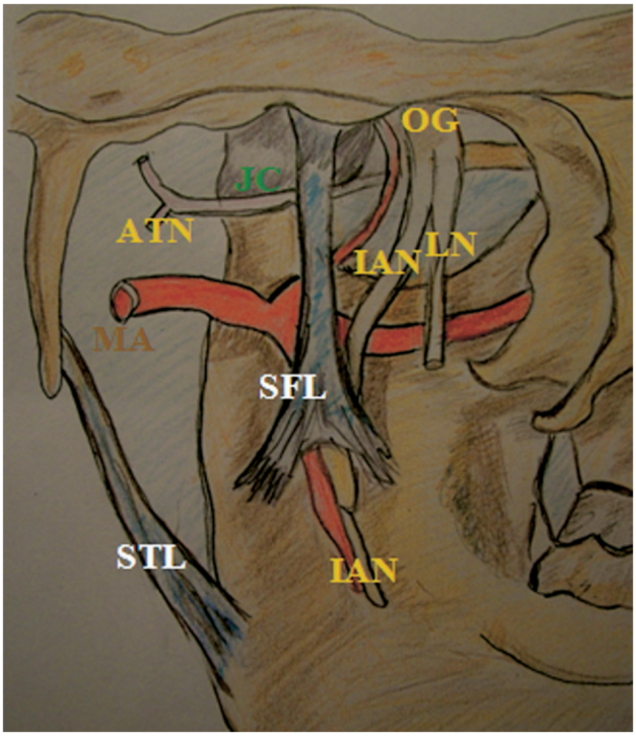

Figure 7 Schematic view of the TMJ ligaments in the central sagittal plane. SFL: Sphenomandibular ligament; STL: stylomandibular ligament; JC: joint capsule; IAN: inferior alveolar nerve; OG: otic ganglion; LN: lingual nerve; ATN: auriculotemporal nerve; MA: maxillary artery. (Color version of figure is available online.)

dyle.[5] In between the two layers, an expansile, soft pad of blood vessels and nerves are sandwiched and wrapped in elastic fibers that aid in contracting vessels and retracting disk in recoil of closing movements. When the mandible is in the closed-mouth position, the thick posterior band lies immediately above the condyle near the 12 o'clock position. The junction of the posterior band and the bilaminar zone should fall within 10 grades of vertical position to be within the 95% percentile of normal. If the angle of displacement exceeds 10 grades, a pathologic condition is considered to be present.[5] Some studies have shown that disk displacement is seen in a large number of asymptomatic volunteers (33%),[6] while authors use the intermediate zone as a point of reference, an approach which does not take into account the angle of displacement of the posterior band.[7]

The retrodiskal attachment tissues are the intra-articular part of the joint posterior to the condyle and the disk. Functionally, the condyle and the disk are seated more anteriorly, being strictly defined when the condyle and the disk are in centric relation. The volume of retrodiskal tissue must increase instantaneously when the condyle translates anteriorly. This tissue is folded and compressed in the joint space when the jaw is in a closed position. When the jaw is opened, the condyle moves down and forward (translates). The upper part of the retrodiskal attachment has a rather prominent vascular shunt and this vascular network is contained within loosely organized fat, collagen, and elastin. Perhaps because the disk tends to merely rotate against the condyle (as opposed to translating, as the disk does against the upper articular surface), the inferior lamina or inferior retrodiskal tissue stretches out and serves to stabilize the disk on the condyle and is composed of relatively inelastic and tightly packed collagen (Fig. 5).

On sagittal MR imaging, the disk appears as a biconcave structure with homogeneous low signal intensity that is attached posteriorly to the bilaminar zone, which demonstrates intermediate signal intensity. The anterior band lies immediately in front of the condyle and the junction of the bilaminar zone, and the disk lies at the superior part of the condyle.[5]

The posterior band and retrodiskal tissue are best depicted in the open-mouth position.[8]

In the coronal plane the posterior band of the disk is identified as low signal intensity tissue above the condyle, while in the axial plane, the anterior band is demonstrated as low signal tissue in front of the condyle. The coronal and axial planes are ideal to demonstrate medial and lateral disk displacement.

Fibrous Capsule

The fibrous capsule is a thin sleeve of tissue completely surrounding the joint. It extends from the circumference of the cranial articular surface to the neck of the mandible. The outline of the capsular attachment on the cranial base can be followed anterolaterally to the articular tubercle, laterally to the lateral rim of the mandibular fossa, posterolaterally to the

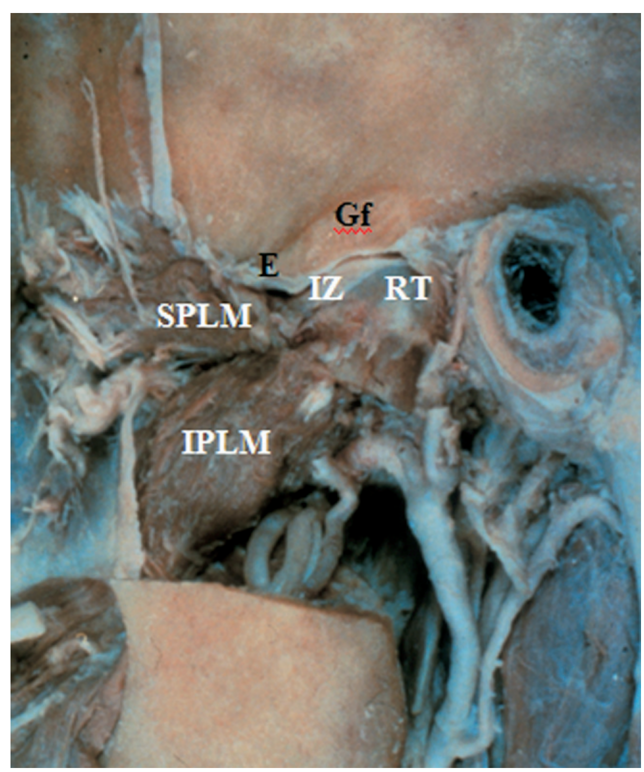

Figure 8 Lateral cadaveric specimen view of the TMJ with removal of the condyle and the cygomatic arch. Gf: Glenoid fossa; E: articular eminence; IZ: intermedius diskal zone; RT: retrodiskal zone; SPLM: superior pterygoid lateral muscle; IPLM: inferior pterygoid lateral muscle. (Color version of figure is available online.)

postglenoid process, posteriorly to the posterior articular ridge, medially to the medial margin of the temporal bone at its suture with the greater wing of the sphenoid, and finally, anteriorly it is attached to the preglenoid plane so as to enclose the same within the joint cavity.[4]

The outline of attachment on the mandibular neck lies a short distance below the edge of the articular surface in front and a considerable distance below the articular margin behind. Laterally, it is attached to the lateral condylar pole but medially it dips below the medial pole.

On the lateral part of the joint, the capsule is a well-defined structure that functionally limits the forward translation of the condyle. This capsule is reinforced more laterally by an external TMJ ligament, which also limits the distraction and the posterior movement of the condyle. Medially and laterally, the capsule blends with the condylodiskal ligaments. Anteriorly, the capsule has an orifice through which the lateral pterygoid tendon passes. This area of relative weakness in the capsular lining becomes a source of possible herniation of intra-articular tissues, and this, in part, may allow forward displacement of the disk[9] (Fig. 5).

Since the articular disk is attached to the inner surface of the capsule, dividing the joint cavity into two compartments, the fibers extend from the condyle to the disk and from the disk to the temporal bone to form two joint capsules. It is important to realize that this capsule is an incomplete structure on the posterior side of the condyle. In fact, the posterior part of the TMJ is bounded by the tympanic plate on the medial two-thirds of the joint and by external ear cartilage on the lateral third.

The synovial membrane lining the capsule covers all the intra-articular surfaces except the pressure-bearing fibrocartilage. The lower and upper compartments form fluid-filled folds (sulci) in marginal gutters of the joint cavity. Thus there are four capsular or synovial sulci situated at the posterior and anterior ends of the upper and lower compartments. These sulci change shape during translatory movements, which requires the synovial membrane to be flexible.[10]

Temporomandibular Ligaments Complex

Collateral Ligaments of the Bilateral Jaw Joints

The ligament on each side of the jaw is designed in two distinct layers. The wide outer or superficial layer is usually fan-shaped and arises from the outer surface of the articular tubercle and most of the posterior part of the zygomatic arch. There is often a roughened, raised bony ridge of attachment on this area. The ligamentous fascicles run obliquely downward and backward to be inserted on the back, behind, and below the mandibular neck. Immediately medial to this layer, a narrow ligamentous band arises from the crest of the articular tubercle continuously, with attachment of the outer portion at this site. This narrow inner or deep band runs horizontally back as a flap strap to the lateral pole of the condyle.

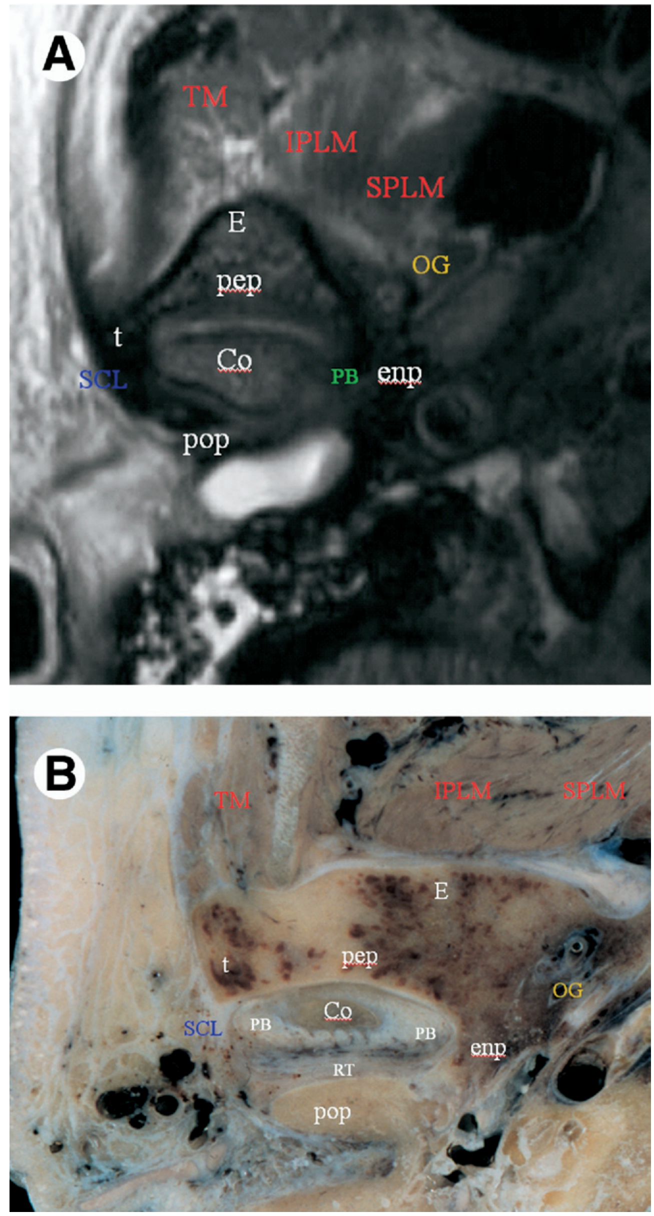

Figure 9 Axial plane of normal anatomy of TMJ, T1 weighted images and cryosectional cadaveric specimen correlation. (A) Craneal plane T1 weighted image. (B) Craneal cryosection image. Osseos and articular components: E: Articular eminence. t: articular tubercule. enp: entoglenoid process. pop: postglenoid process. pep: preglenoid plane. Cp: condilar process. Gf: glenoid fossa. Co: mandibular condyle. Capsular disc and articular components. AB: anterior band. IZ: intermedius band. PB: posterior band. 4: anterior recess. 5: posterior recess. IL: inferior lamina. TL: temporal lamina. RT: retrodiscal zone. FC. fibrous capsule. Muscular components: TM: temporal muscle. IPLM: inferior bell of lateral lateral pterygoid muscle. SPLM: superior bell of lateral pterygoid muscle. PMM: medial pterygoid muscle. MM: masseter muscle. Ligaments and vascular components: FN: branchs of facial nerve. ATN: auriculotemporal nerve. IAN: inferior alveolar nerve. LN: lingual nerve. OG: otic ganglion. MA: maxillary artery. MV: maxillary vessel. MMA: maxillary artery. STV: superficial temporal vessels. SCL: superficial collateral ligament. DPL: deep collateral ligament. SFL: Sphenomandubular ligament. STL: Stylomandibular ligament. (Color version of figure is available online.)

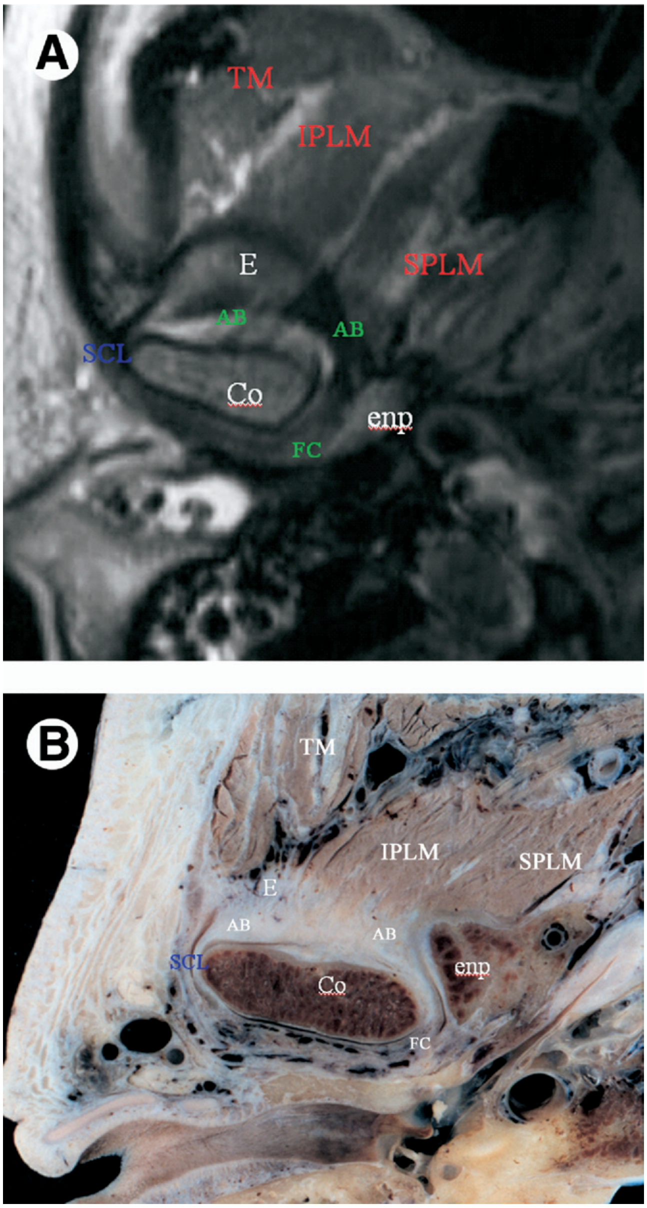

Figure 10 (A) Middle plane T1 weighted image. (B) Middle plane cryosection image. (Color version of figure is available online.)

An upper part of this band continues on to attach to the back of the disk, lateral to the condylar pole.

Medial slippage of the condyle is prevented medially by the entoglenoid process and laterally by the temporomandibular ligament.

The outer oblique band becomes taut in the protraction of the condyle, which accompanies the opening of the jaw, thereby limiting the inferior distraction of the condyle in forward gliding and rotational movements, while the inner horizontal band tightens in retraction of the head of the mandible, thereby limiting posterior movement of the condyle[11] (Fig. 6).

Sphenomandibular Ligament

This ligament arises from the angular spine of the sphenoid and petrotympanic fissure and then runs downward and outward to insert on the lingula of the mandible.

The ligament is related laterally to the lateral pterygoid muscle, with the auriculotemporal nerve running posteriorly, the maxillary artery running anteriorly, the inferior alveolar nerve and vessels running inferiorly and entering the mandibular foramen and a lobule of the parotid gland, and finally, medially to the medial pterygoid with the chorda tympani nerve and the wall of the pharynx with fat and the pharyngeal veins intervening. The ligament is pierced by the myelohyoid nerve and vessels. This ligament is passive during jaw movements, maintaining relatively the same degree of tension during both opening and closing of the mouth.

Stylomandibular Ligament

This is a specialized dense, local concentration of deep cervical fascia extending from the apex and being adjacent to the anterior aspect of the styloid process and the stylohyoid lig-

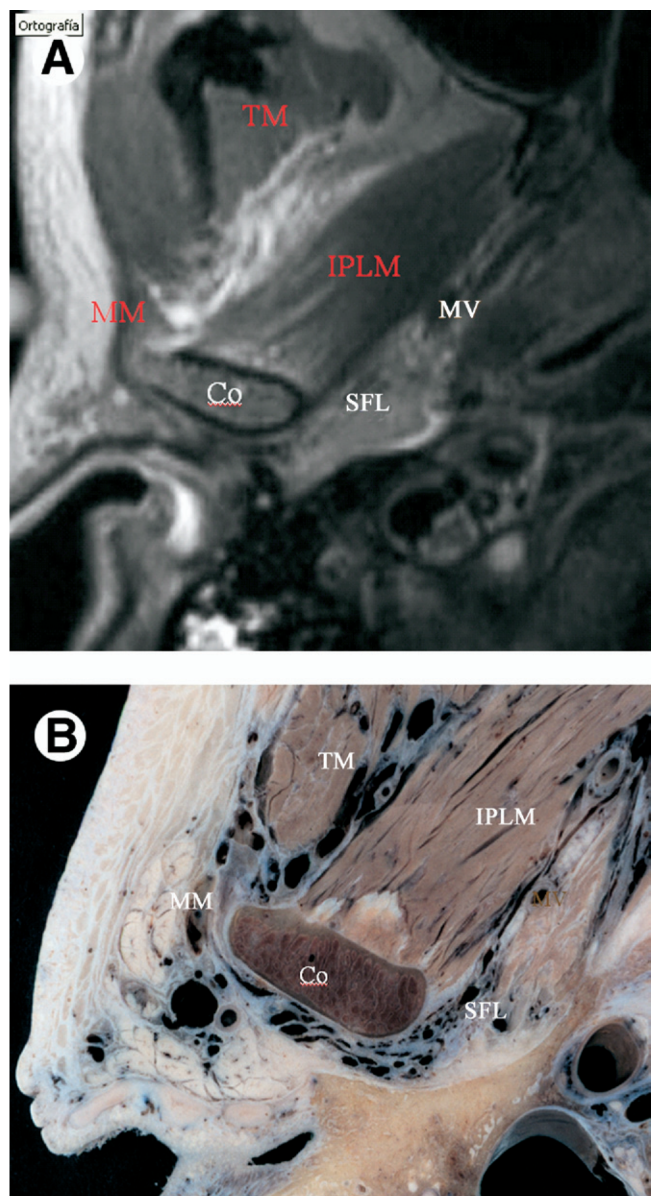

Figure 11 (A) Caudal plane T1 weighted image. (B) Caudal plane cryosection image. (Color version of figure is available online.)

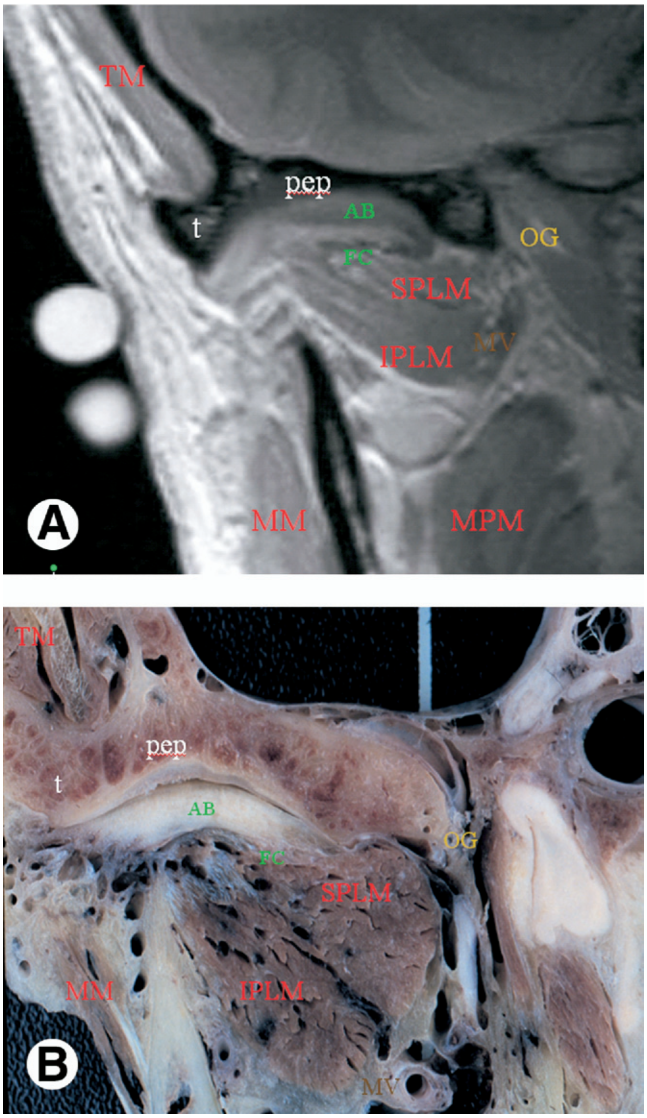

Figure 12 Paracoronal plane of normal anatomy of TMJ, T1 weighted images and cryosectional cadaveric specimen correlation. (A) Anterior plane T1 weighted image. (B) Anterior cryosection image. (Color version of figure is available online.)

ament to the mandible's angle and posterior border. This ligament then extends forward as a broad fascial layer covering the inner surface of the medial pterygoid muscle. The anterior edge of the ligament is thickened and sharply defined. It is lax when the jaws are closed and slackens noticeably when the mouth is opened because the angle of the mandible swings up and back while the condyle slides downward and forward. This ligament becomes tense only in extreme protrusive movements. Thus, it can be considered only as an accessory ligament of uncertain function (Fig. 7).

Muscular Component

Since so many TMJ problems involve the muscles, it is extremely helpful to know their names and how they work. The masticatory muscles surrounding the joint are groups of muscles that contract and relax in harmony so that the jaws function properly. When the muscles are relaxed and flexible and are not under stress, they work in harmony with the other parts of the TMJ complex. The muscles of mastication produce all the movements of the jaw. These muscles begin and are fixed on the cranium extending between the cranium and the mandible on each side of the head to insert on the mandible.

Different muscles are therefore required for the opposite movements of the mandible. The muscles of mastication are abductors (jaw openers) and adductors (jaw closers). The temporalis, masseter, and medial pterygoids muscles are adductors, while the lateral pterygoids muscles are the primary abductors of the jaw. The muscles that produce forward movement (protrusive) are also used alternately to move the jaw from side to side (laterally).

The principal and strongest muscle of mastication is the masseter, which stems from the temporal bone and extends down the outside of the mandible to its lower angle, with a broad insertion along the lateral border of the conyle.

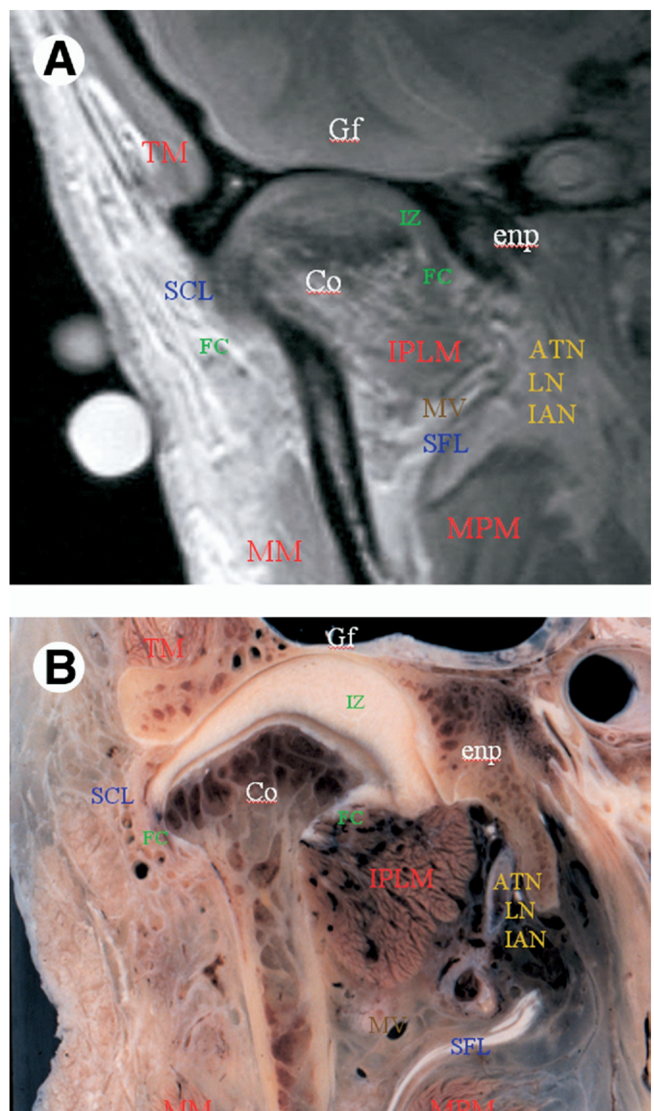

Figure 13 (A) Middle plane T1 weighted image. (B) Middle plane cryosection image. (Color version of figure is available online.)

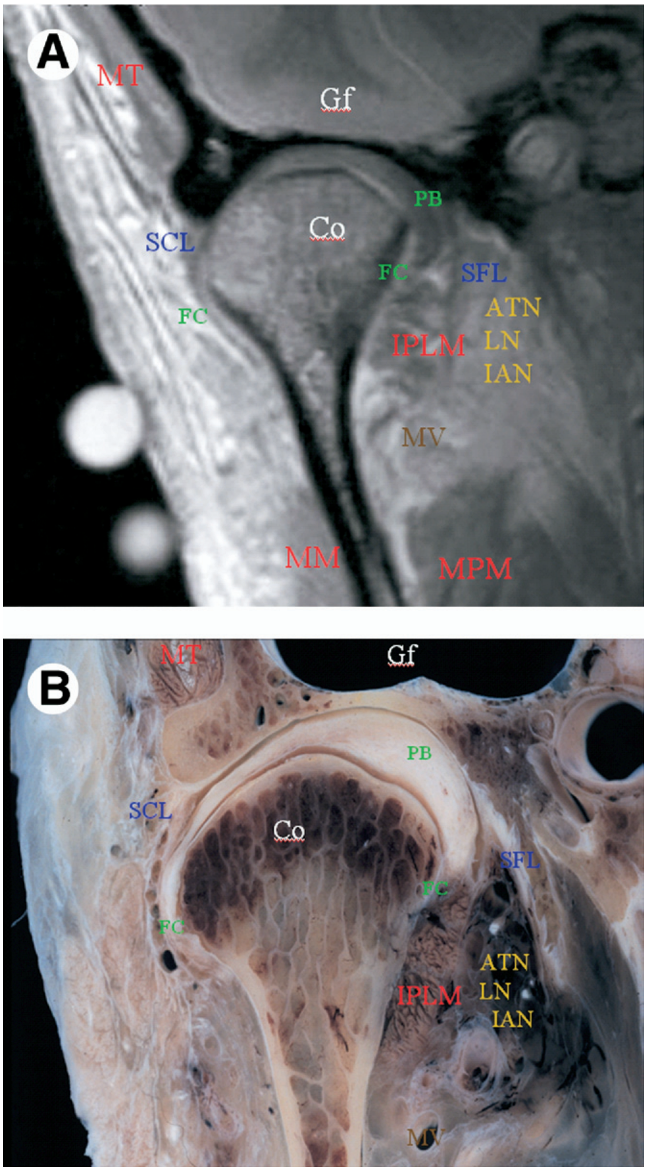

Figure 14 (A) Central plane T1 weighted image. (B) Central plane cryosection image. (Color version of figure is available online.)

The second muscle for closing is the medial pterygoid, which runs parallel to the masseter but on the inside of the jaw. It originates at a wing-shaped protrusion of the cranium. This and the masseter muscle form a sling around the back end of the mandible and work together to pull it shut.

The third muscle for closing is the temporalis. It looks like a partially spread fan on the side of the head. It has a broad end that originates high on the temporal fossa and temporal fascia, while its narrow end inserts on the coronoid process of the lower jaw.

When you chew, you not only move your mouth vertically, but also forward and backward (protrusively) and from side to side (laterally). These movements are largely produced by the pair of lateral pterygoid muscles. These muscles originate from the same regions of the cranium as the medial pterygoid muscles and extend backward and outward (laterally) toward the condyles. The lateral pterygoid is composed of two portions or bellies, the superior belly (upper) and the inferior belly (lower).

The pair of inferior bellies are primarily responsible for moving the jaw forward, thus, opening the mouth, and pulling the mandible to one side. The inferior belly is predominately attached to the top of the lower jaw (mandibular condyle). When these bellies contract, they pull the condyles forward out of the fossa and down to the lowest points of the eminences. Contracting alternately, the inferior bellies allow the jaw to move laterally. This movement also takes place spontaneously when the mouth is opened wide.

The superior belly fibers pass through the joint capsule and connect with the front of the articular disk. The supe-

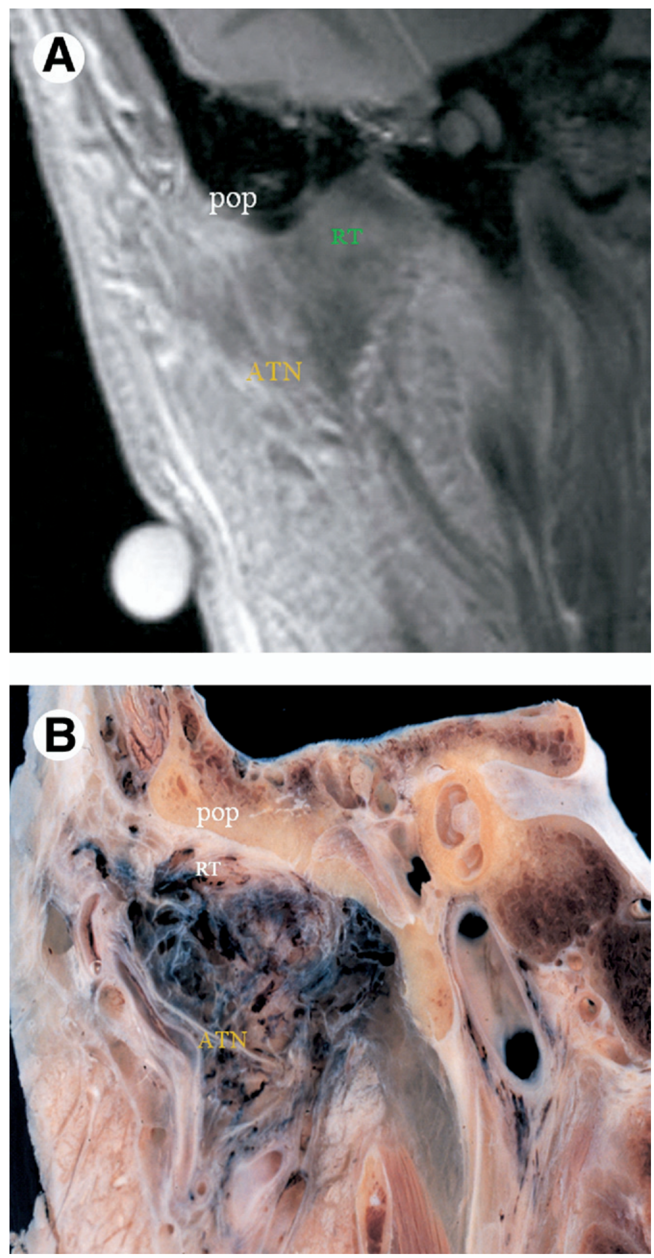

Figure 15 (A) Posterior plane T1 weighted image. (B) Posterior plane cryosection image. (Color version of figure is available online.)

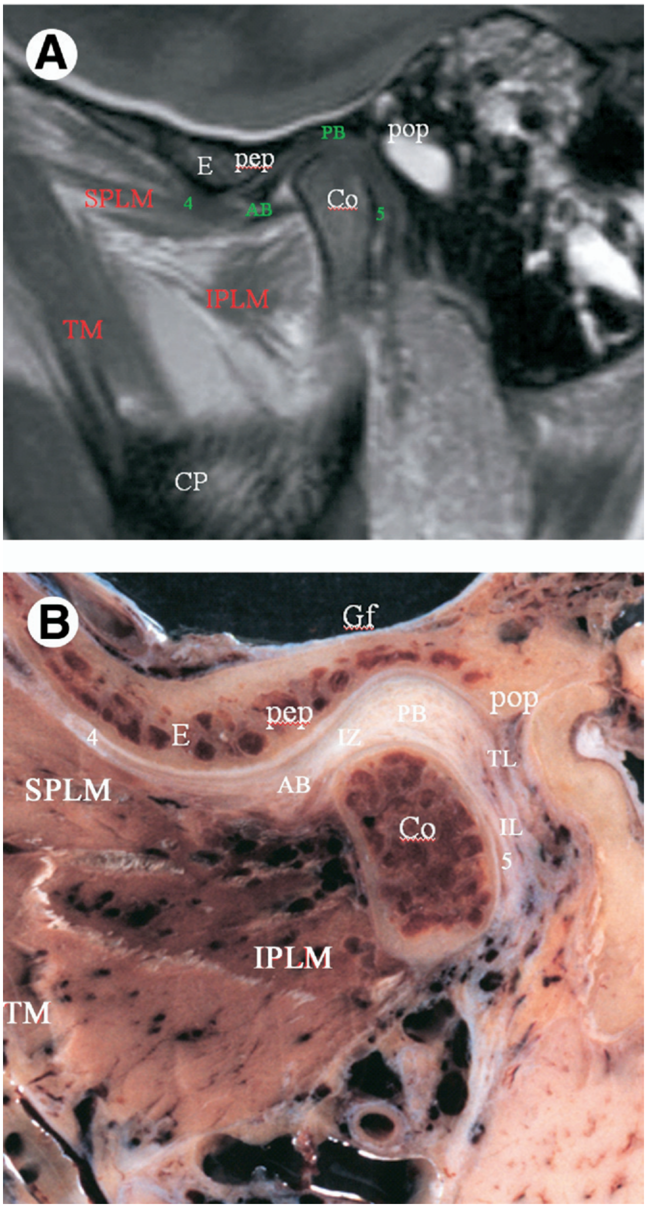

Figure 16 Parasagital plane of normal anatomy of TMJ, T1 weighted images and cryosectional cadaveric specimen correlation. (A) Medial sagittal plane T1 weighted image. (B) Medial sagittal cryosection image. (Color version of figure is available online.)

rior belly is responsible for proper disk movement in coordination with movement of the lower jaw, especially when closing the mouth, just the opposite of the inferior belly. It then exerts forward pressure on both the condyle and the disk, stabilizing their relationship to each other and assuring the most effective position possible when the strong forces of chewing move the condyle backward and forward (Fig. 8).

Lubrication of the Joint

The synovial fluid comes from two sources: first, from plasma by dialysis, and second, by secretion from type A and B synoviocytes with a volume of no more than 0.05 ml. However, contrast radiography studies have estimated that the upper compartment could hold approximately 1.2 ml of fluid without undue pressure being created, while the lower has a capacity of approximately 0.5 ml.[10]

Blood Supply

The venous pattern is more diffuse, forming a plentiful plexus all around the capsule. Posteriorly, the retrodiskal pad is copiously riddled with wide venous channels. These cavernous spaces fill and empty as the condyle rocks rhythmically forward and backward, providing for unhampered, nimble movement in normal joint action. A similar venous feature is also seen anteriorly but to a lesser degree.

Teeth and Occlusion

The way the teeth fit together may affect the TMJ complex. A stable occlusion with good tooth contact and interdigi-

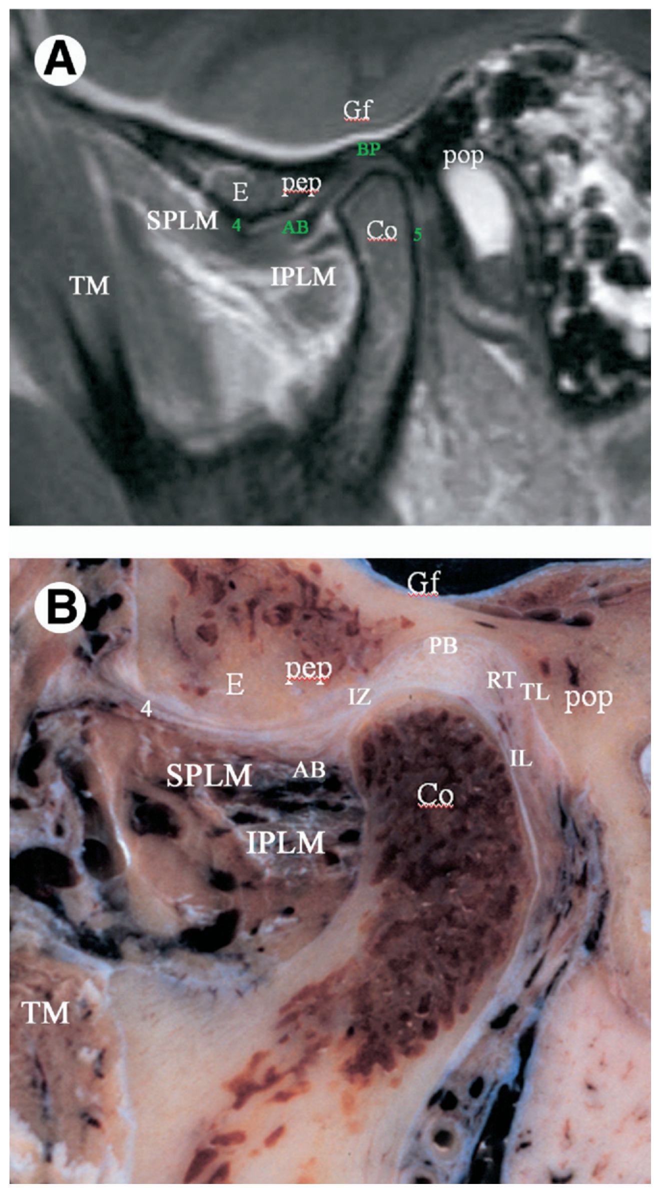

Figure 17 (A) Middle sagittal plane T1 weighted image. (B) Middle sagittal plane cryosection image. (Color version of figure is available online.)

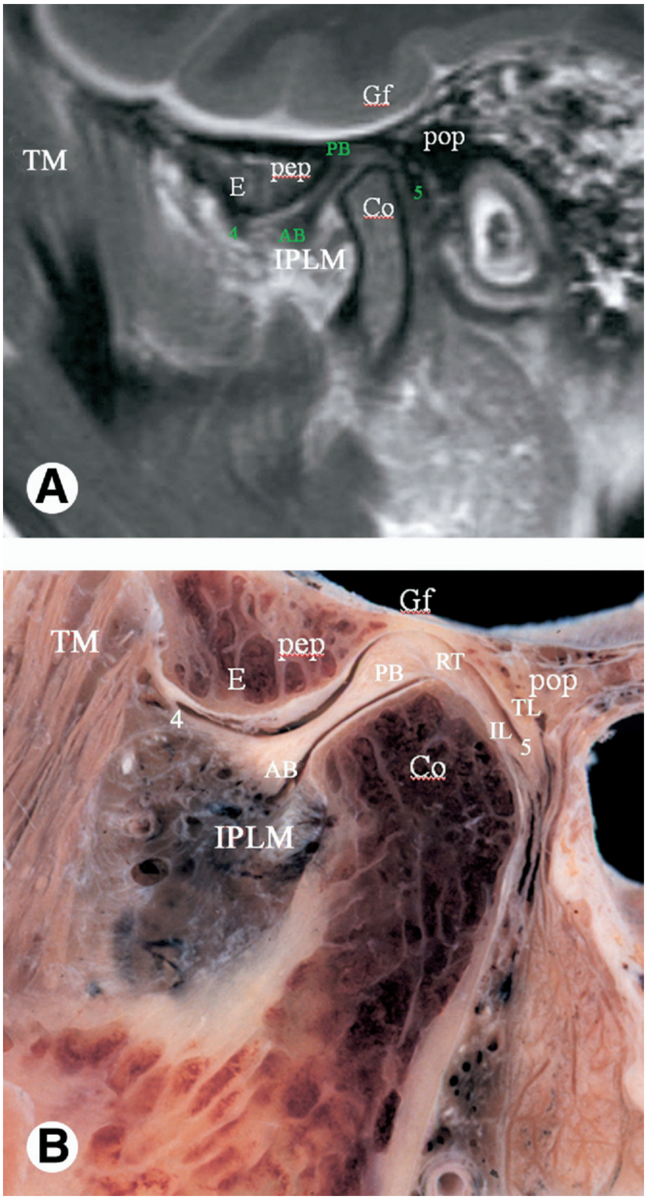

Figure 18 (A) Lateral sagittal plane T1 weighted image. (B) Lateral sagittal plane cryosection image. (Color version of figure is available online.)

tation provides maximum support to the muscles and joint, while poor occlusion (bite relationship) may cause the muscles to malfunction and ultimately cause damage to the joint itself. Instability of the occlusion can increase the pressure on the joint, causing damage and degeneration.

Technical Note

We obtained parasagittal, paracoronal, and axial MR images of fresh, asymptomatic TMJ autopsy specimens and compared the MR images with corresponding parasagittal, paracoronal, and axial cryosections of the joints. The specimens were taken from cadavers with a cosed-jaw intercuspal position based on natural teeth.

MR imaging was performed with a 1.5-T MR imaging system (Excelart, Toshiba, San Francisco Inc) with the body coil as transmitter and the 6.5 cm diameter dedicated to the TMJ surface coil as a receiver. With this configuration, relatively uniform object excitation was achieved with the large body coils, while the smaller, sensitive volume of the surface coil allowed the signal-to-noise ratio to be increased in the vicinity of the coil.[12-14]

Tree axial planes images of normal anatomy of temporomandibular joint in T1-Weighted images and cryosectional anatomy. (Figs. 9, 10 and 11), four paracoronal planes images (Figs. 12, 13, 14 and 15) and four parasagital planes images (Figs. 16, 17, 18 and 19) are compared.[15]

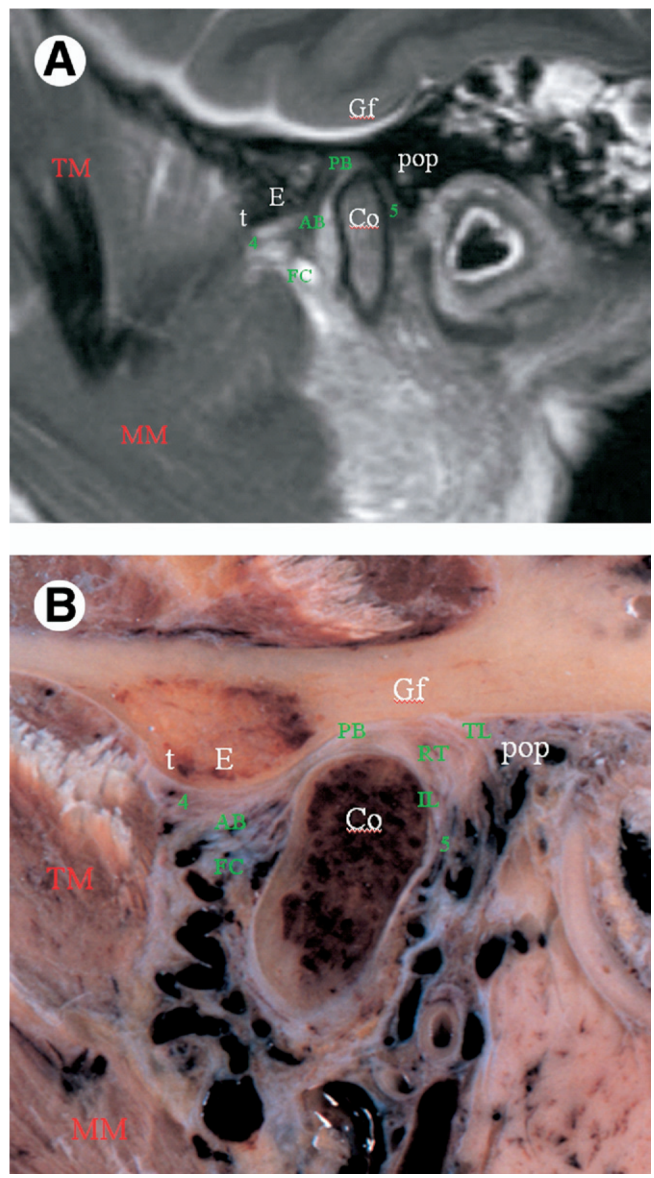

Figure 19 (A) Periferic sagittal plane T1 weighted image. (B) Periferic sagittal plane cryosection image. (Color version of figure is available online.)

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